Pencil Beam Scanning Proton Therapy Planning with 3D and 4D Robust Optimization Versus Photon IMRT for Lung Cancer

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INTRODUCTION

To investigate the effects of lung tumor size on photon and proton planning comparison, and to evaluate the robustness of 3D and 4D optimization for proton pencil beam scanning plans.

METHOD

Three categories of ten lung tumor patients were evaluated: A) Prescription 50Gy(1250cGyx4) early stage SBRT, with peripheral lung tumor diameter 2cm-4.5cm; B) Prescription 60Gy(750cGyx8) hypo fractionated treatment(HIGRT), with central lung tumor 2.5-6cm; C) Prescription >60Gy(200cGyx30) advanced stage lung tumors.

Previously treated photon IMRT/VMAT plans covers Rx>95%PTV. For category A) and B), all planning target volumes (PTV) included 5mm expansion to the internal target volume (ITV). Proton planning IGTVs (union of 10 phases) were the same as photon ITVs. For C) PTV included the CTV plus 5mm margin expansion.

RESULTS

Three planning strategies were implemented to generate proton plans based on Monte Carlo calculation with RayStation(V8bSP1) proton planning pencil beam scanning system (PronovaSC360), with/without Robustness Optimization (RO). The 3D optimization was done on ITV for average CT, and 4D optimization (4% range uncertainty, 5mm setup uncertainty) was implemented for GTV (or CTV) on each individual breathing phase. Each phase-GTV and all plans were examined by physicians to ensure optimal target coverage and OAR constrains. The comparison among photon and proton plans for three tumor types were evaluated, the proton plans (no-RO/3D-RO/4D-RO) were compared. Selected results were presented in Figure1 and Table1-2.

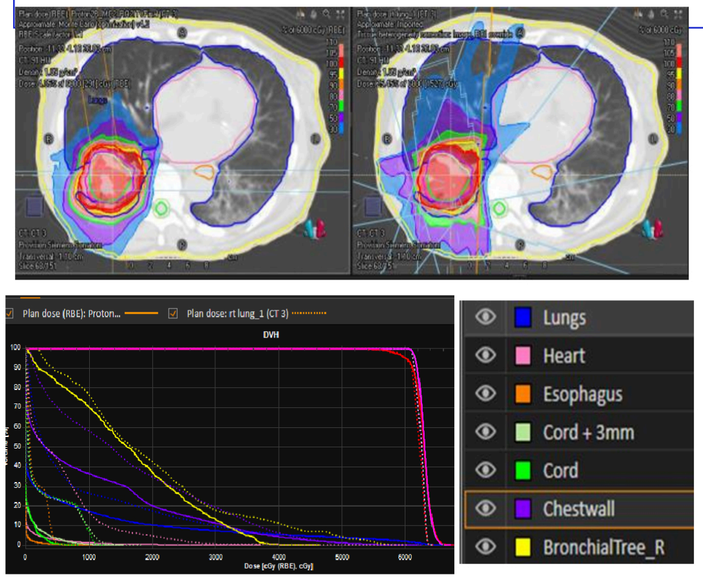

Figure1: An example of original IMRT photon plan (Top Right), Proton plan with 3D robustness optimization (Top Left) for HIGRT plans (category B patient, Rx 60Gy-7.5Gyx8). Both photon and proton plans achieve Rx 60Gy at 95% Volume of PTV and 99% Volume of ITV on Average CTs as nominal plans. Proton plans spares more lung, heart, Bronchial tree, Esophagus, Chest Wall and Cord dose. Bottom: DVH comparison: Bold line-proton plan with 3D RO; Dash line-photon plan.

Patient Category and Number	Tumor Size, equivalent sphere diameter	Planning strategies	PTV coverage Rx (%)	ITV coverage Rx (%)	Cord Max (Gy)	Chest Wall V30Gy (cc)	Skin Max (Gy)	Lung V20 Gy (%)	Lung Mean (Gy)	Esophagus Max (Gy)	Heart Mean (Gy)
A) SBRT 50Gy		A) Prescription 50Gy(1250cGyx4) for early stage SBRT, Peripheral lung tumor									
A3	4.5cm	Proton RO	95.2%	100%	7.9	70cccc	28.3	4.6	4.6	0.5	0
		Photon	94.7%	99.9%	10.7	101cc	34	8.7	8.7	8	3.0
B) HIGRT 60 Gy (750cGy x 8)		B) Prescription 60Gy(750cGyx8) HIGRT for central lung tumor within 2cm of proximal bronchi									
		Planning strategies	PTV coverage Rx (%)	ITV coverage Rx (%)	Cord Max (Gy)	Bronchial Tree Max (Gy) <60Gy		Lung V20 Gy (%)	Lung Mean (Gy)	Esophagus Max <40 (Gy)	Heart Mean (Gy)
B1	2.7cm	Proton RO	96.3%	100%	2.0	64.5		6.4	3.8	10.4	0.2
		Photon	94.2%	100%	13.0	65.9		3.9	3.6	16.4	2.3
B5	4.7cm	Proton RO	95.5%	99.3%	0	24.4		7.04	3.2	17.2	3.7
		Photon	94.7%	99.5%	8.6	55.2		7.82	4.7	17.6	12.4
C) Normal fractionated 60 Gy (2Gyx30)		Prescription 60Gy(200cGyx30) for advanced stage lung tumors									
		Planning strategies	PTV coverage Rx (%)	ITV coverage Rx (%)	Cord Max (Gy)	Lung V20 Gy (%)		Lung Mean (Gy)	Esophagus V60Gy (%) <20cc	Esophagus Max (Gy)	Heart Mean (Gy)
C1	6.0cm	Proton RO	97.8%	100%	17.8	18.8		9.1	18.3cc	61.7	3.0
		Photon	96.4%	100%	27.5	23.3		13.8	10.2cc	62.0	6.4

Table 1: Comparison of Target and Organ at Risks planning results among the three categories of 10 lung cancer patients A) Prescription 50Gy(1250cGyx4) early stage SBRT, with peripheral lung tumor diameter 2cm-4.5cm; B) Prescription 60Gy(750cGyx8) HIGRT with central lung tumor 2.5-6cm; C) Prescription 60Gy(200cGyx30) for advanced stage lung tumors..

Planning strategies	PTV V60Gy (%) on Average CT	ITV V60Gy (%) on Average CT	ITV Rx 99% (Gy) on Average CT	GTV D99% (Gy) Max Inspiration	GTV D99% (Gy) Max Expiration	GTV D99% (Gy) Mid-Phase	PTV V60Gy (%) Max Inspiration	PTV V60Gy (%) Max Expiration	PTV V60Gy (%) Mid-Phase
Photon Plan	95.3%	99.5%	60.54	No Robustness calculation for photon plan on individual phase, planning with PTV with 5mm expansion to ITV on average CT					
Proton 3D RO	96.55%	99.96%	60.99	60.64	61.43	61.14	96.34%	97.12%	97.62%
Proton 4D RO	98.41%	99.99%	60.24	61.37	61.53	61.63	98.71%	98.63%	98.56%

Table2. An example of comparison of original IMRT photon plan (Right), Proton plan without robustness optimization, proton plan with 3D Optimization (3D RO), and proton plan with 4D Optimization (Left) for target coverage on average CT (nominal plan). All proton plans implemented with Single field optimization.

CONCLUSIONS

For tumor size larger than 4cm diameter, the optimized proton plans demonstrated the superior OAR sparing compared to photon plans; higher target coverage was achieved with the 4D robust optimization proton planning method over 3D robustness optimization.

REFERENCES

1. Four-dimensional Plan Optimization for the Treatment of Lung Tumors Using Pencil-beam Scanning Proton Radiotherapy, Cureus. 2018 Aug; 10(8): e3192.Published online 2018 Aug 23. doi: 10.7759/cureus.3192

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